Hand Out: 10/10
Due: 10/17

UNIVERSITY OF CALIFORNIA
College of Engineering
Departments of Mechanical Engineering and Material Science & Engineering

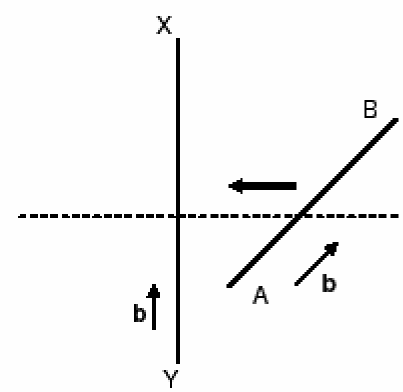
Prof. Ritchie

MEc124 / MSEc113
Mechanical Behavior of Materials

<u>Problem Set #4 – 33 points</u>

Problem 1

a) The two screw dislocation (AB and XY) will intersect as sketched below. Draw AB and XY after the intersection has occurred, specifying the magnitude of each jog and its nature. Will either dislocation be impeded upon subsequent motion at ambient temperature?



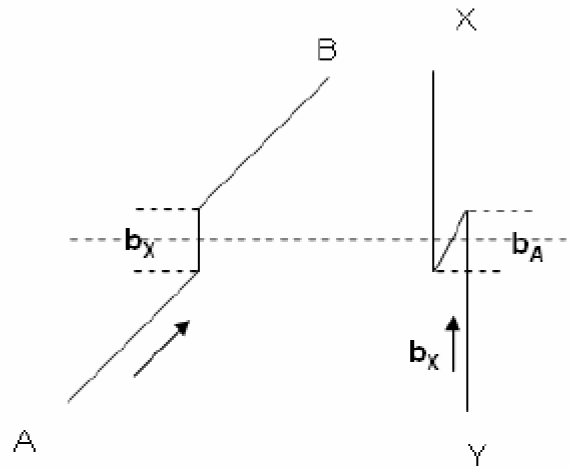
b) Estimate the contribution to the tensile yield strength if a BCC steel alloy is hardened by a distribution of precipitates 0.04 *μm* in diameter with an average spacing of 0.15 *μm*.

G (Shear Modulus) = 11600ksi
? (Poisson's ratio) = 0.3
a (lattice spacing) = 1.14 10^{-8} in

Solution 1 – 10 points

a) After intersection

$\boxed{5}$



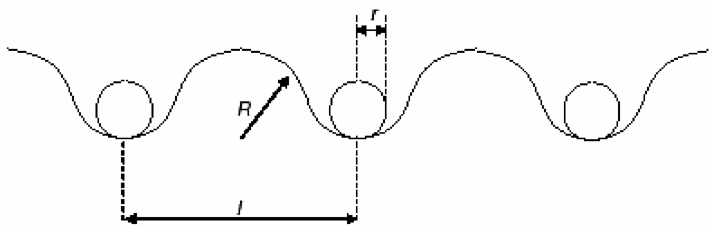
The JOGS on both AB and XY are edge in character since $\bar{l} \perp \bar{b}$

The remainder of each dislocation is still screw in character since $\bar{l} \parallel \bar{b}$

Both dislocations will be impeded upon subsequent motion since the edge portions are confined to their individual slip planes. In order for AB or XY to move left or right, the edge portions must climb. Climb requires vacancy diffusion (and so thermal activation). Therefore, at ambient temperatures, AB and XY are effectively pinned.

b)

5



$$\begin{aligned} G &= 11600 ksi \\ a &= 1.14 \times 10^{-8} m \\ l &= 0.15 \times 10^{-6} m = 5.91 \times 10^{-6} in \\ r &= 0.02 \times 10^{-10} m = 7.87 \times 10^{-7} in \end{aligned}$$

$$\tau_{BOW} = \frac{Gb}{2R} \quad R = \frac{l-2r}{2} = 2.17 \times 10^{-6} \tag{1}$$

Reasonable to assume $R \approx l/2$, but the above expression is a little more exact.

In BCC structure,

$$\begin{aligned} \bar{l} &= \frac{a}{2} < 1\,1\,1 > \\ |barb| &= \sqrt{\left(\frac{a}{2}\right)^2 + \left(\frac{a}{2}\right)^2 + \left(\frac{a}{2}\right)^2} = \frac{\sqrt{3}}{2} a = \frac{\sqrt{3}}{2}(1.14 \times 10^{-8} in) \\ |barb| &= 9.87 \times 10^{-9} in \end{aligned}$$

$$\tau = \frac{111600 \times 10^3 lb/in^2 \times 9.87 \times 10^{-9} in}{2(2.17 \times 10^{-6})} \tag{2}$$

t = 25.4 ksi

Problem 2

List the various metallurgical factors, which can be utilized to induce high creep resistance. Contrast these factors with those that might be utilized for high strength at temperatures, $T < 0.3\ T_m$. Also, do some library research as to how polymers and ceramics are different from metals with respect to creep (make sure you list the references you use).

Suggested Solution 2 – 10 points

Since creep is a diffusion-assisted process, metallurgical factors that can slow down the diffusion will be beneficial to creep resistance. This is achieved by

1) **increasing the diffusion distance**, e.g. Using coarse-grained structures or single crystals
2) **choosing materials** with low diffusion rate or high diffusion activation energy
3) **increase melting temperature**
4) **preserving hardening mechanisms** that are effective at temperatures less than $0.3\ T_m$

The hardening of metallic materials at $T < 0.3\ T_m$ is achieved by various mechanisms that act to impede the dislocation slip. These mechanisms include:

1) **Solid solution hardening** where the strain fields associated with the solute atoms interact with the dislocation or solute atoms form an atmosphere surrounding the dislocation. The mechanism is not effective at high temperature because the stress\strain fields of solutes will be relaxed or solute atmosphere around the dislocation will diffuse away from dislocations and, therefore, cannot be used to induce high creep resistance.
2) **Strain hardening** resulting from dislocation-dislocation interaction, which forms immobile jogs or sessiles. At high temperature, these immobile jogs or sessiles can climb easily and, therefore, cannot act as barriers to dislocation motion.
3) **Grain refining** which reduces the stress concentration produced by dislocations piled up at grain boundaries. This is detrimental to creep resistance because the diffusion distance is shortened and area fraction of grain boundaries is increased, which facilitate grain sliding.
4) **Precipitation hardening** from pinning of dislocation by precipitates. This mechanism can be used as an effective way to increase creep resistance if the precipitates can be mad stable at high temperatures.

Comments regarding creep resistance of ceramics or polymers could be related to deformation mechanisms in these materials (or the lack thereof). Polymers can withstand large plastic deformations before fracture, whereas ceramics have very little (to no) plasticity. Polymeric deformation occurs by “untangling” of molecules so they are aligned along the load direction.

Problem 3

A support rod in a boiler carries a constant tensile stress of 10 ksi. The rod is made from a medium carbon steel with a creep behavior as shown in the figure below and obeys the dimensionless creep equation:

$$\frac{\dot{e}_{11}}{\dot{e}_0} = \left(\frac{s_{11}}{s_0}\right)^m e^{\frac{-H(s_{11})}{kT}}$$

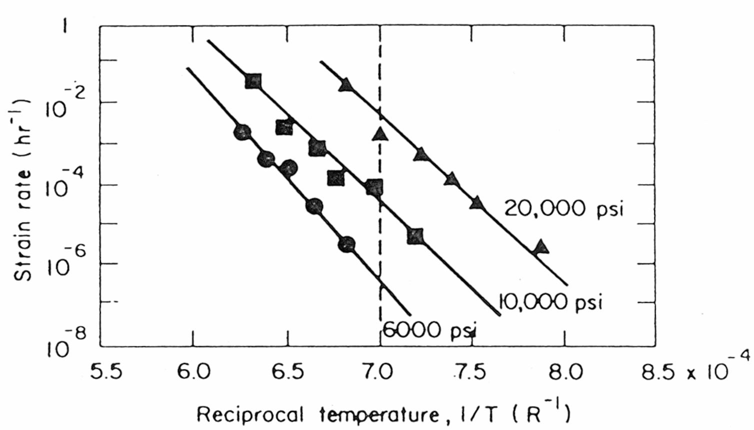
where s_0 is a constant and $H(s_{11})$ the activation energy for creep.

a) What is the activation energy for creep at each stress?

b) Find m, the creep exponent.

c) Find s_0, the normalizing stress.

d) If this rod elongates more than 10% is must be replaced. What is the lifetime if the boiler operates at 1000°F (°R = °F + 460)?



Solution 3 – 13 points

a) Based on the dimensionless creep equation we can find the activation energy, which is based on the slopes in the given creep graph.

$$H(s_{11}) = -k\left[\frac{\Delta \ln\left(\frac{\dot{e}_{11}}{\dot{e}_0}\right)}{\Delta\left(\frac{1}{T}\right)}\right]_{s_{11}=const.}$$

H (6 ksi) = 7.8 x 10^{-18} in lb

H (10 ksi) = 6.8 x 10^{-18} in lb

H (20 ksi) = 6.6 x 10^{-18} in lb

Note: depending on how accurate one reads the graphs, these numbers might vary a little.

b) The creep exponent, *m*, can be found from this data, since:

$$m = \left[\frac{\Delta(\ln(\dot{e}_{11}))}{\Delta \ln(s_{11})}\right]_{T=const.}$$

This is assuming *H* is approximately equal at all three (6, 10, 30 ksi) stresses

By substituting: (6,000; 10^{-6}), (10,000; 10^{-4}), (20,000; 10^{-6}) (at ~1460R) and calculating the slope of the $\ln(s_{11}), \ln(\dot{e}_{11})$ curve, it follows that m ~ 7.16

Note: depending on how accurate one reads the graphs or on how you chose to average the slopes this numbers might vary a little.

c) Now that we've found *H* and *m*, s_0 is the only unknown, so we can solve for s_0 with the dimensionless creep equation:

$$s_0 = s_{11}\left(\frac{\dot{e}_0}{\dot{e}_{11}}\right)^{1/m} e^{\frac{-H}{mkT}}$$

Using the reference point: $\dot{e}_{11}$ = 1 x 10^{-4} hr^{-1} , s_{11} = 10,000 psi, T = 1460 °R (or any other point in the graph):

s_0 = 2.5 psi

Note: depending on your answers in a), b) and c) this number might vary.

d) Since $\dot{e}_{11}$ = constant and e_{11} = 0.1

$$t = \frac{e_{11}}{\dot{e}_{11}}$$

Substituting this into the dimensionless creep equation:

$$\dot{e}_o = 1$$

$$\dot{e}_{11} = \left(\frac{s_{11}}{s_0}\right)^m \exp\left(\frac{-H}{kT}\right) = \left(\frac{10000}{2.5}\right)^{7.16} \exp\left(\frac{-6.8*10^{-18}}{6.79*10^{-23}*1460}\right) = .0001$$

$$t = \frac{.1}{.0001} = 1000$$

Creep life is 1000 hours.